Structural Materials Progress

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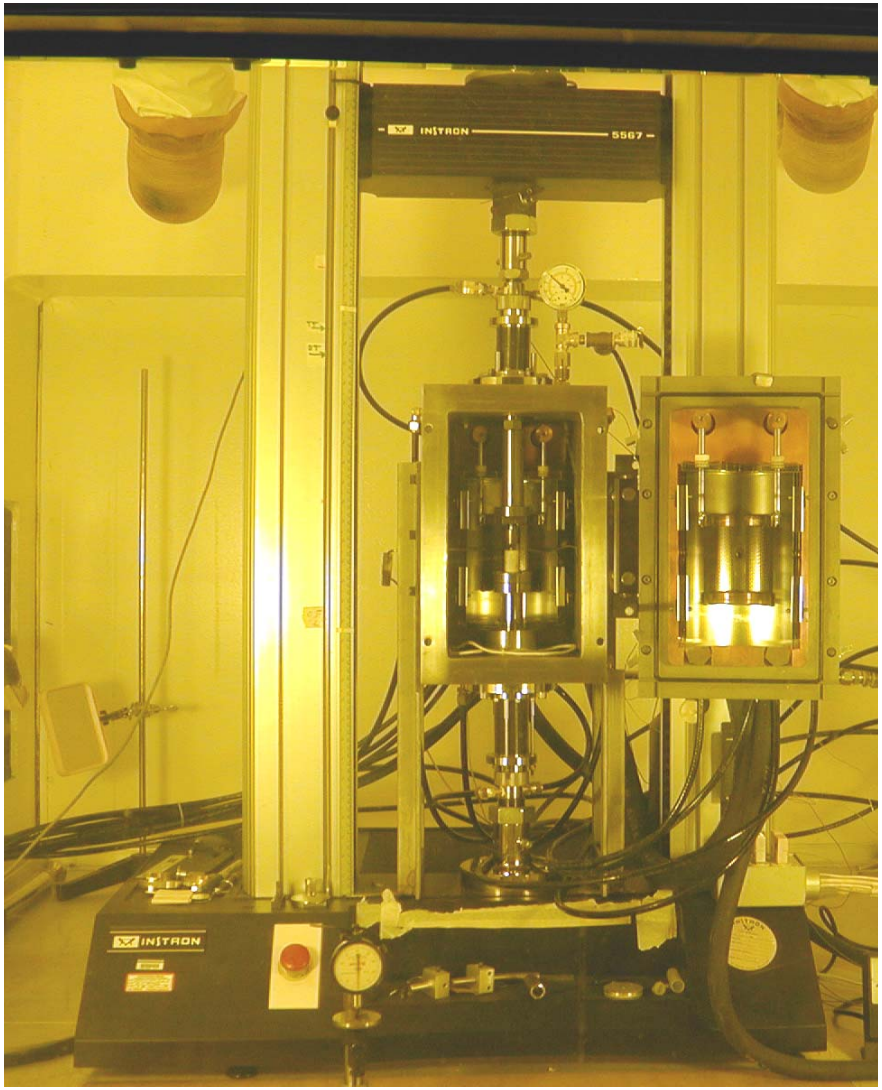
Highlights

- **Mechanical Testing and Microstructure**
  - High Temp. testing of proton irradiated 9Cr-1Mo and 316L
  - TEM analysis of proton irradiated microstructure
  - Shear punch testing of 316L at 300C
  - Installation of 700C furnace in LANL CMR hot cell on mechanical test machine
  - High Temp. compression on proton irradiated tungsten at 500C
- **Data**
  - Produced Rev. 3 of Materials Handbook
    - » Added T91 chapter
    - » Added LBE chapter
    - » Added corrosion information on 316L, 718, W and Al6061 in water under proton irradiation
    - » Added proton irradiation effects on tungsten
  - Held TRADE target workshop in November 2003
- **Modelling-**Use MD methods to understand the effect of He and H on irradiation damage in BCC-Fe.
- **Blue Room Tests**
  - In Situ Corrosion- Measured corrosion of T91 and 316L in LBE.
  - Cavitation Erosion tests in LBE

Goals/Objectives

- Determine the effect of high energy proton and neutron irradiation on the mechanical properties of structural materials for the AFCI project under prototypical conditions of irradiation temperature and flux.
  - Irr. Temperature 400-600ºC
  - Total fluence up to 200 dpa
  - Materials
    - » T91, HT-9, EP823
    - » 316L
    - » Backup solid target-tungsten/tantalum
- Use mechanical test data to determine structural design allowables for AFCI components.
- Support Gen IV materials program

Mechanical Testing Capabilities



Recently Installed Furnace in LANL hot cell

Hardness Testing

Leitz Metallograph in hot cell

Vickers indentor

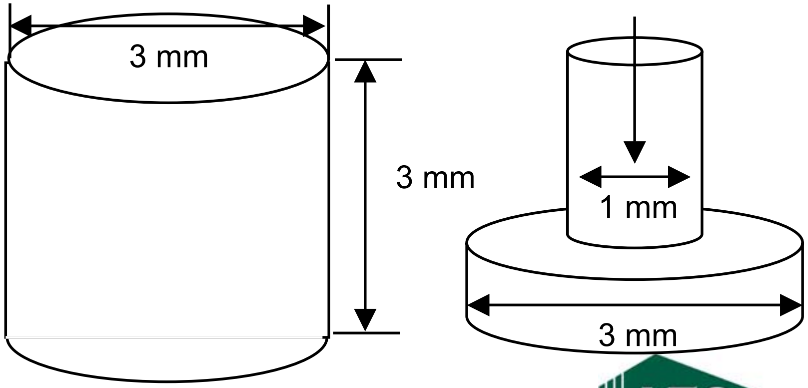
50-400g load

Instron 5567 testing machine in Hot Cell:
Temperature capabilities- RT to 700ºC in argon (**upgradable to 1200C with minor changes**)

Strain Rate- 10^{-3}/s

Mechanical tests- 3 pt. bend, tensile, shear punch and compression

Material tested- Tungsten



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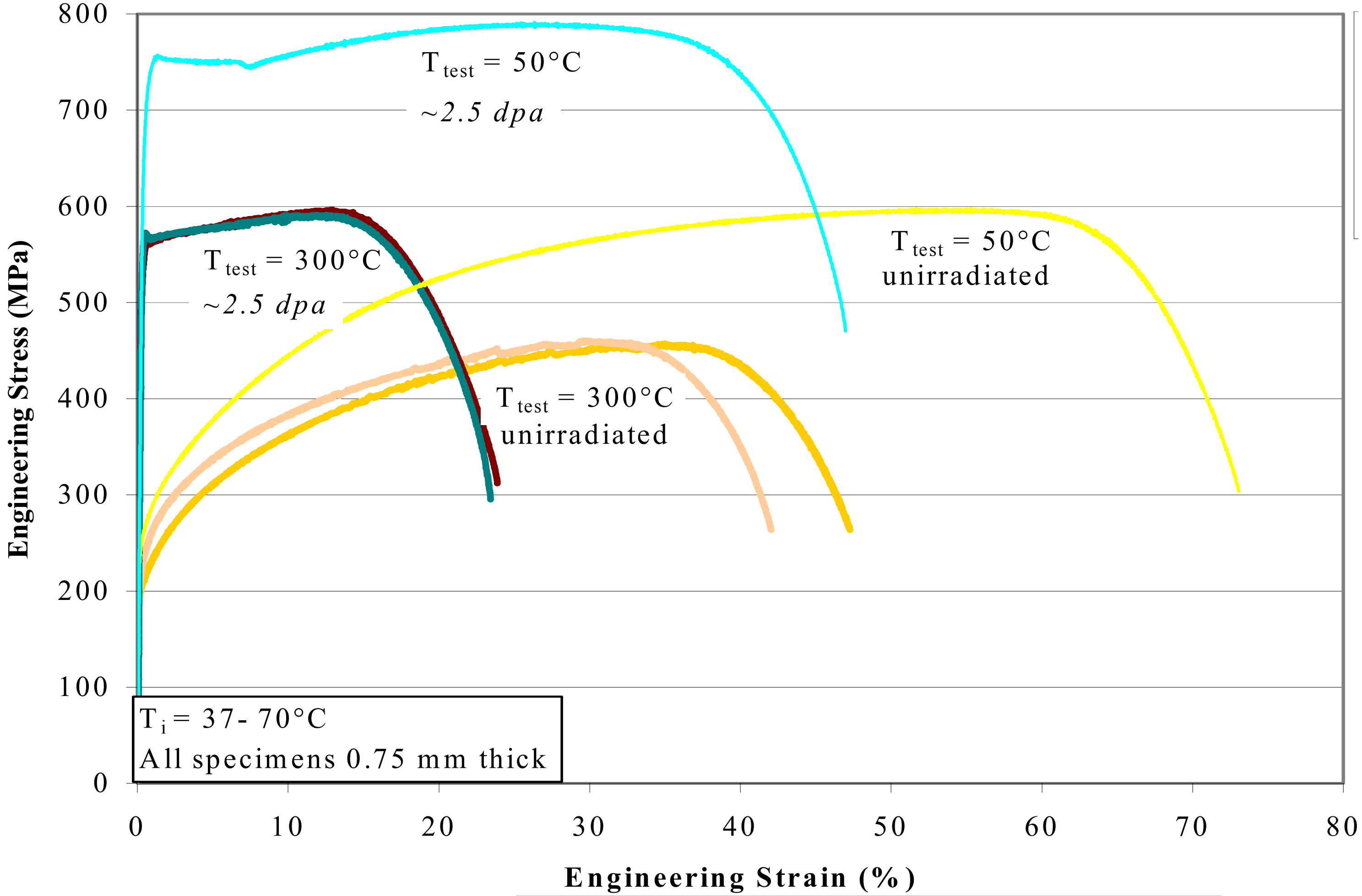
Testing of 316L Stainless Steel at 300°C Shows Reduced Ductility Compared to 50°C Test Temperature



Similar results when performed on fission neutron irradiated materials

Tirr	Ttest	Dose	UE	Yield	Reference
60	25	19	20	747	Pawel FRM
60	330	19	10	596	Pawel FRM
35	55	5.5	23.5	799	Wiffen, JNI
35	300	4.5	16.2	526	Wiffen, JNI

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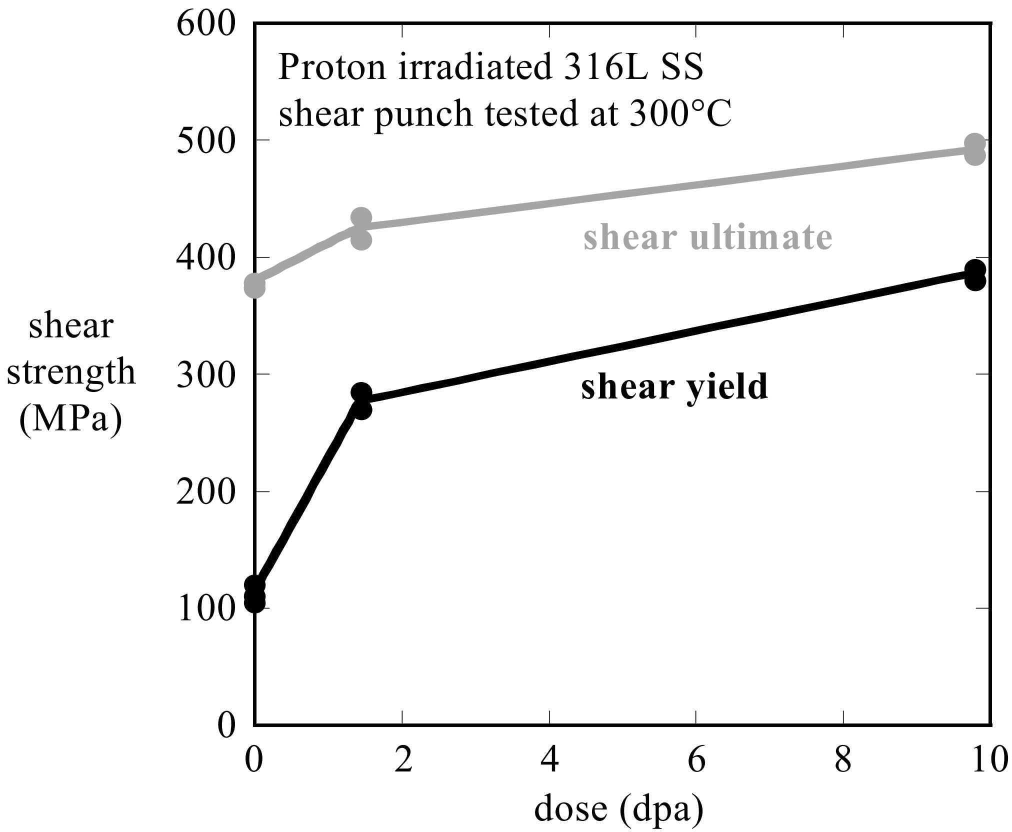
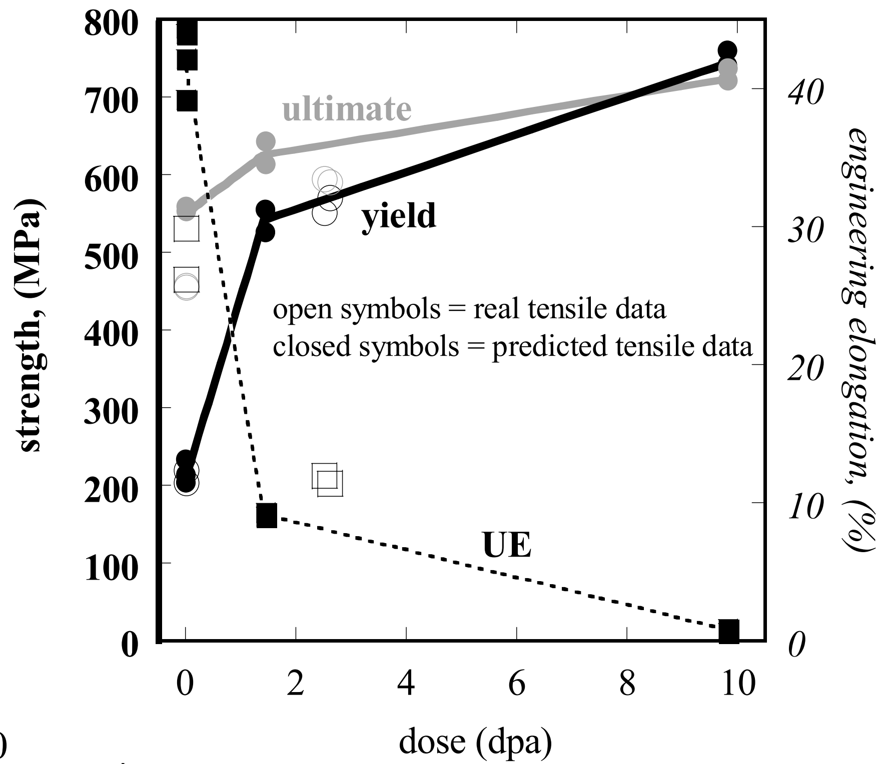
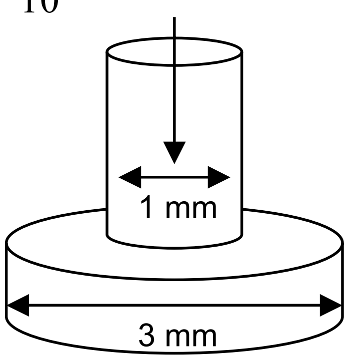
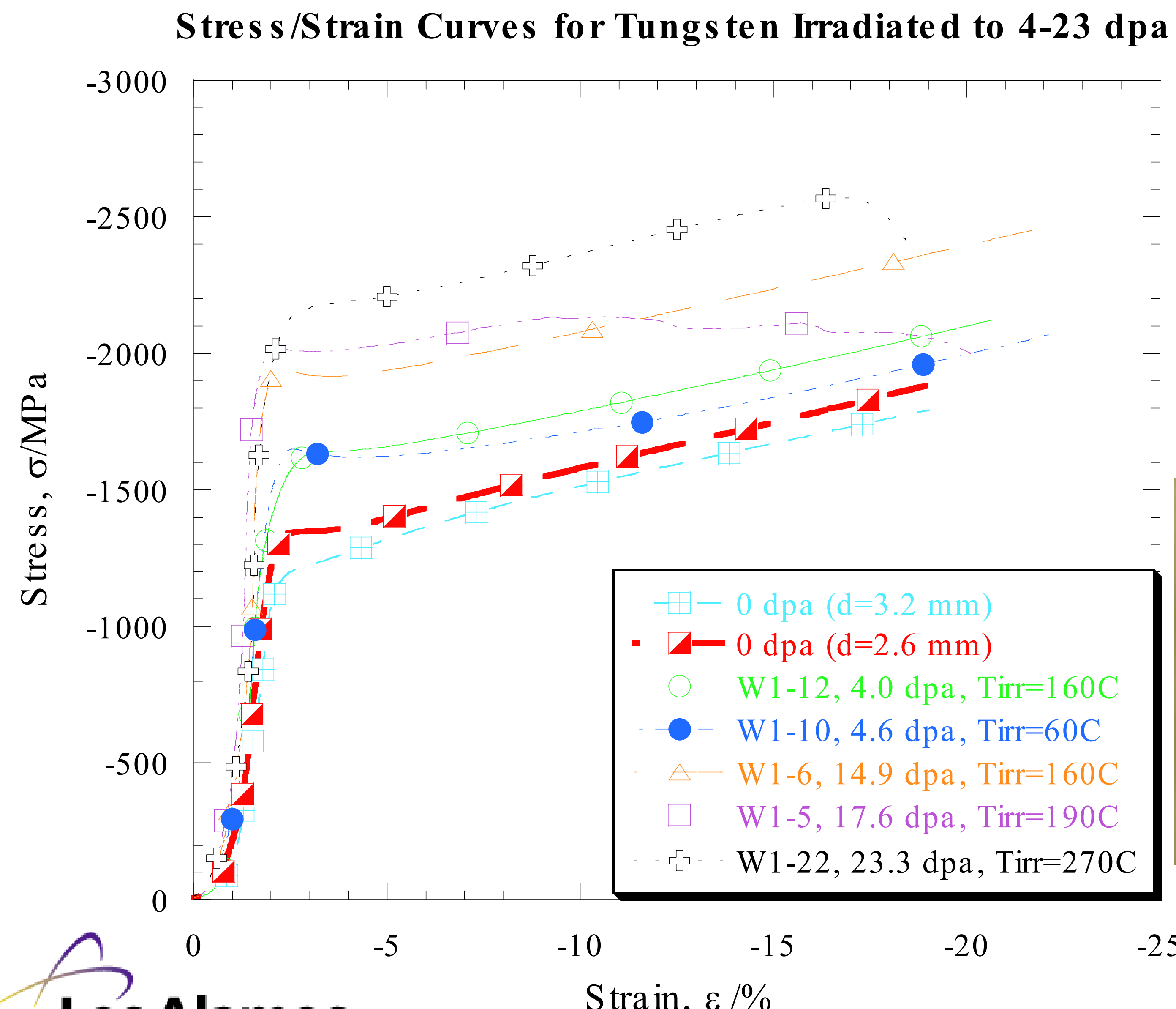
High Temperature Shear Punch Testing of 316L Stainless Steel Predicts Ductility Loss at 10 dpa

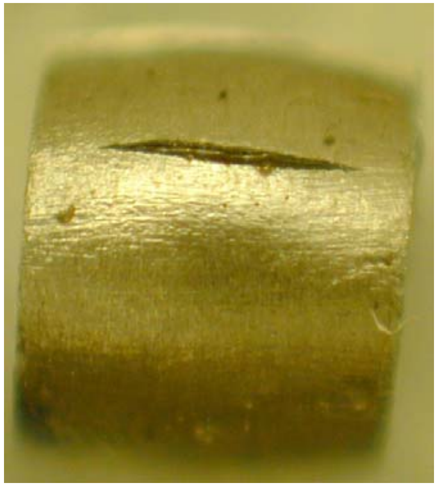




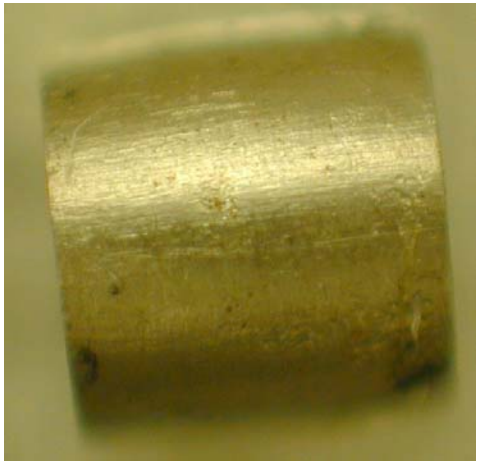


Compression Stress/Strain Results for Irradiated Tungsten Show Increase in Yield Stress with Dose above 4 dpa



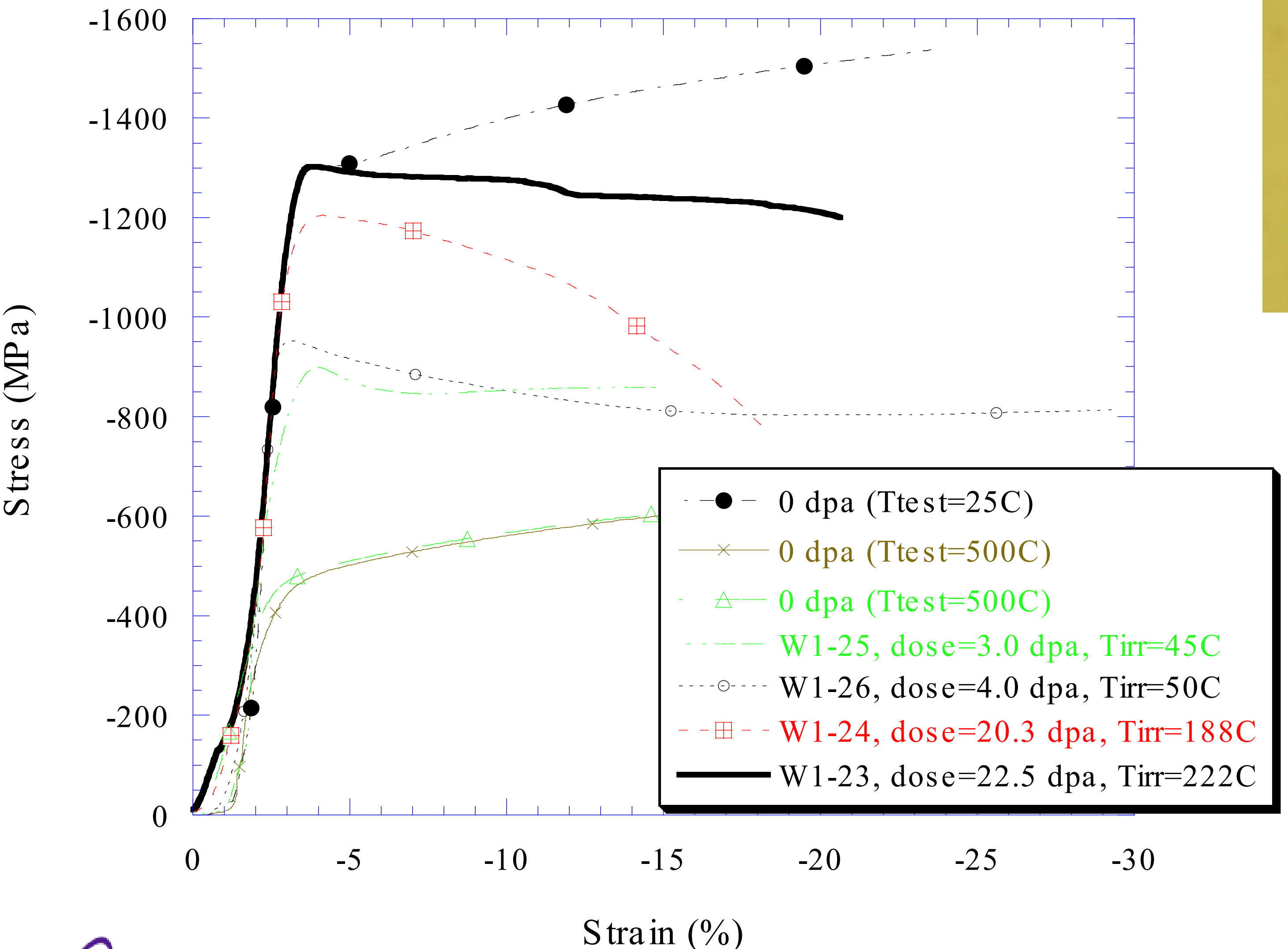


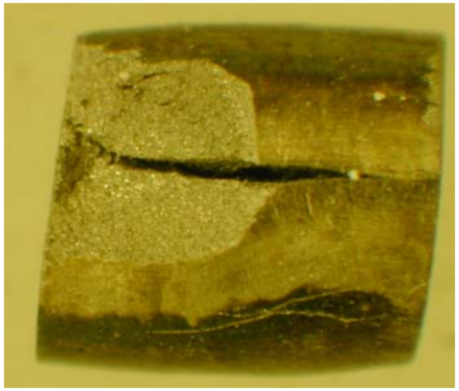
3.2 dpa



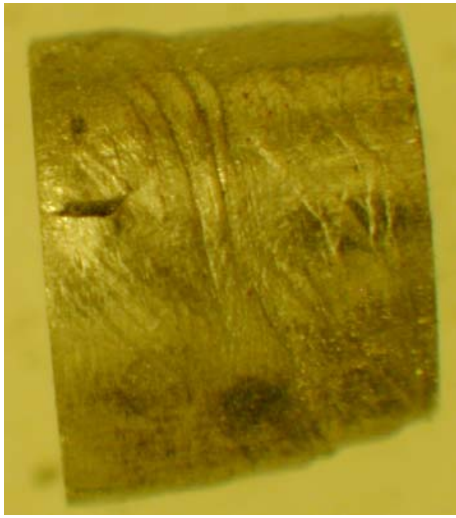
0 dpa

Test Results on Compression Testing of Tungsten at 500C



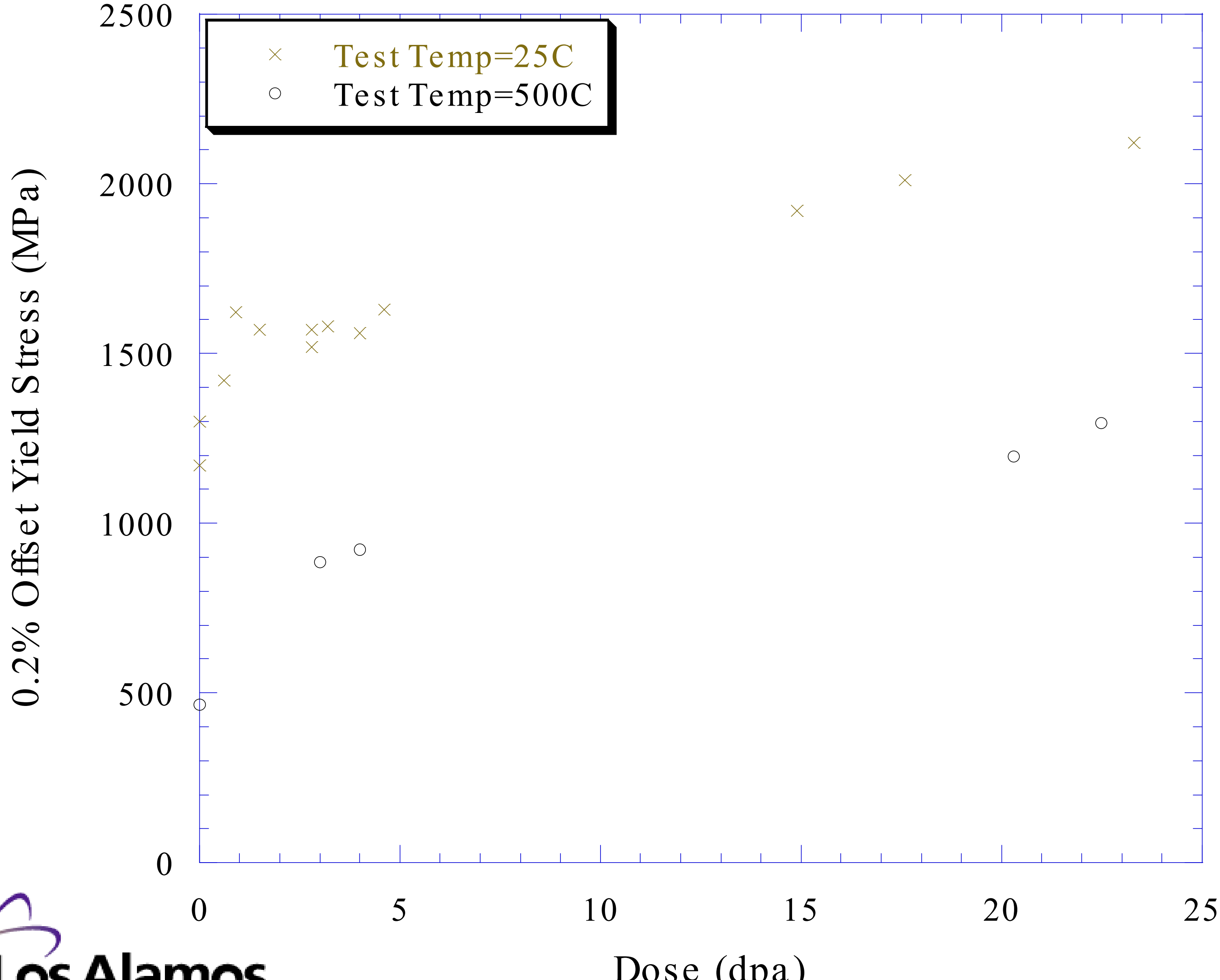


Dose=22.5 dpa



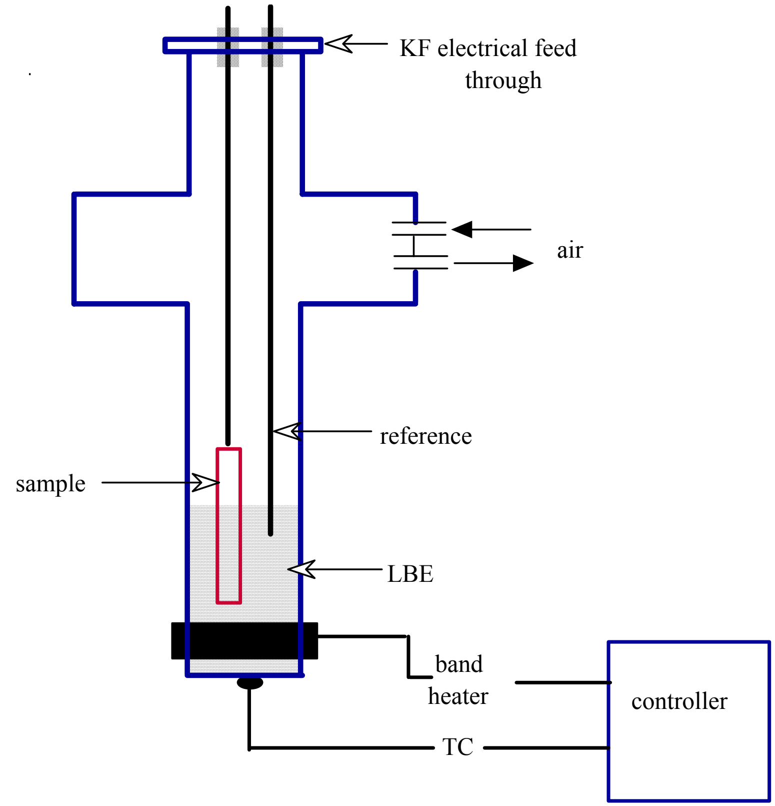
Dose=3.0 dpa

Yield Stress steeply with dose up to 1 dpa and gradually up to 23 dpa



In Beam Corrosion Results

- Both HT-9 and SS 316L were tested in the WNR experiments.
- These samples were prepared by polishing to 4000 p and sequentially cleaning in acetone, ethanol, and DI water.
- This was followed by oxidation in moist air at 800° C for 48 hrs for HT-9 and 70 hrs. for SS 316L.
- Following grinding, cleaning, and preoxidation the samples were subsequently immersed in LBE (no irradiation) for up to 72 hrs.



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In Beam Corrosion Results

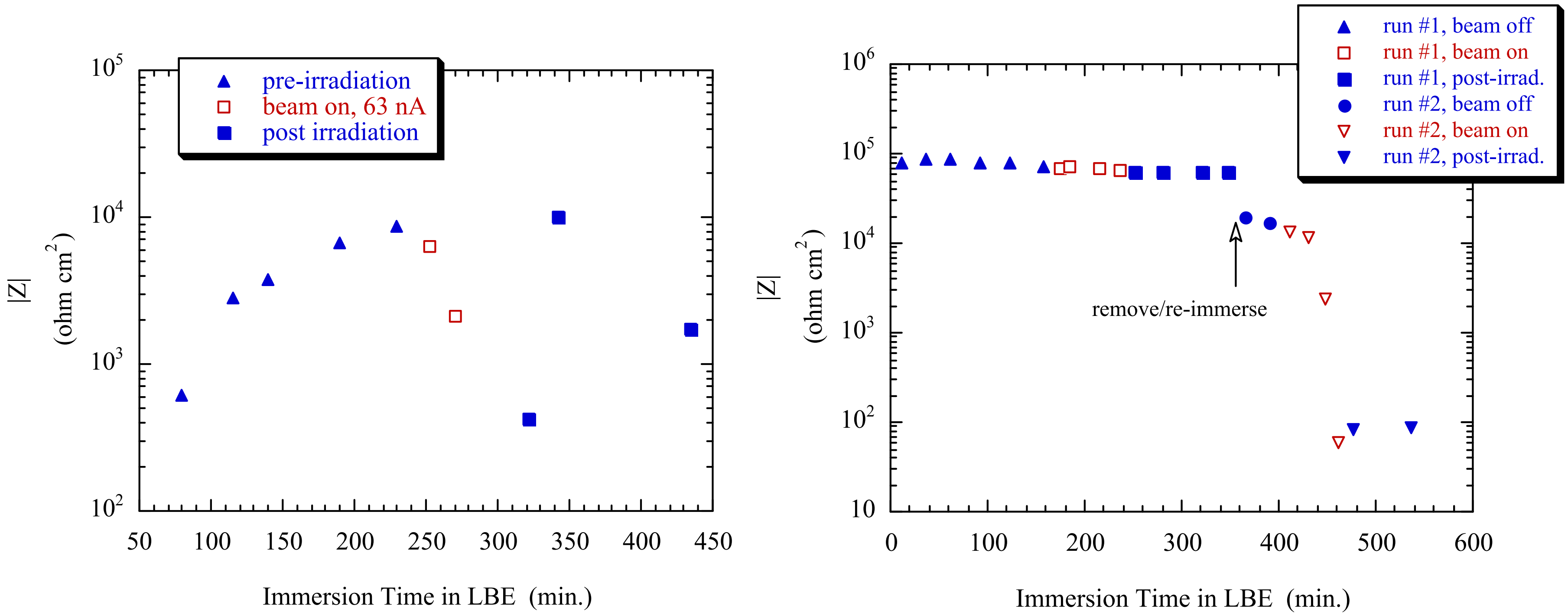

Figure 7 Oxide impedance as a function of LBE immersion time for a pre-oxidized HT-9 sample (48 hrs. @800° C). Plot shows pre-irradiation, irradiation and post-irradiation data.

The observed decrease in oxide impedance during proton irradiation may be explained by local or global changes in oxide film properties. However, a small pinhole that allowed LBE to com in direct contact with the metal substrate is unlikely as the contact impedance in LBE as measured in the laboratory was on the order of 0.5 Ω and the film impedance after irradiation was on the order of 15 - 320 Ω·cm^2.

Liquid Lead-Bismuth Eutectic Target

- **Liquid lead-bismuth target was subjected to a pulsed proton beam at WNR Blue Room facility.**
  - **200 pulses at 800MeV with about 30 second intervals.**
  - **Pulse length was about 0.25μs.**
  - **10mm diameter beam spot.**
- **Reason:**
  - **The shock wave created by fast local thermal expansion of liquid metal due to proton pulse may cause cavitation damage on the target internal surface.**
  - **SNS mercury targets experienced such damage.**

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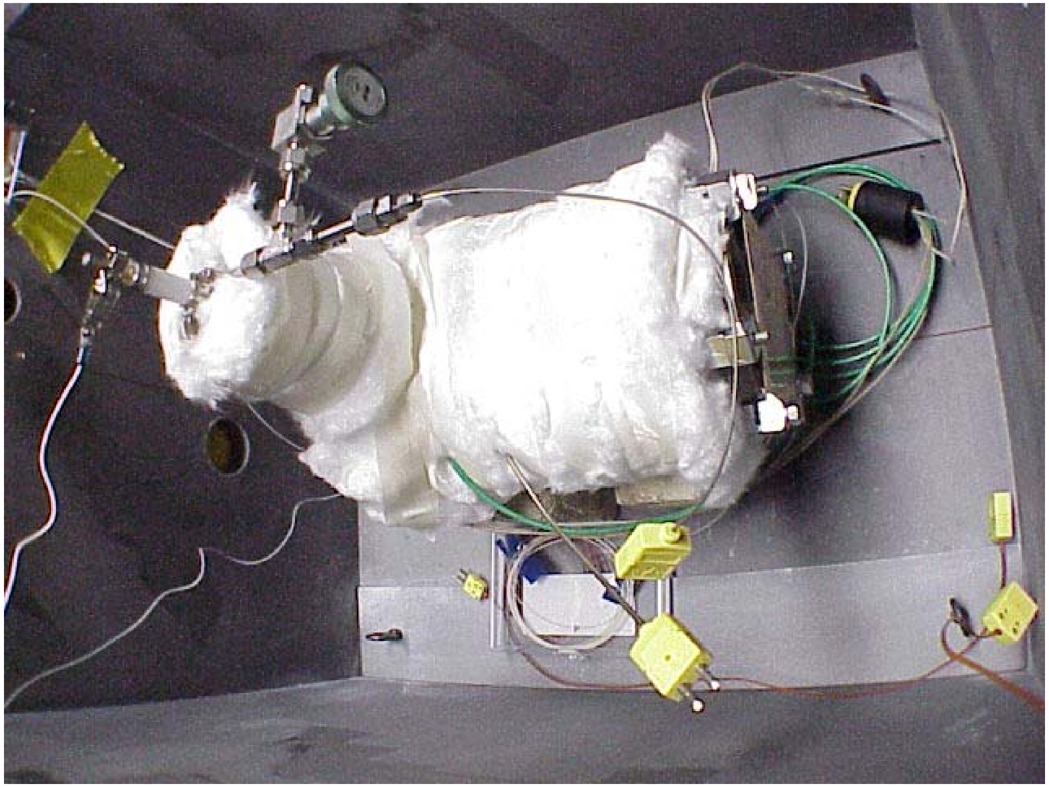
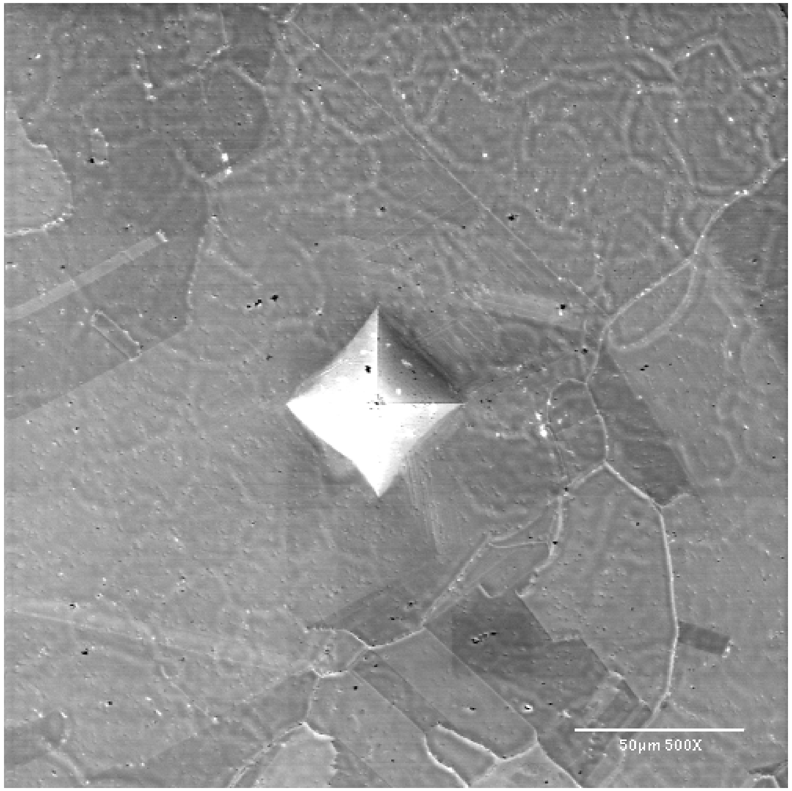
Liquid Lead-Bismuth Target for WNR

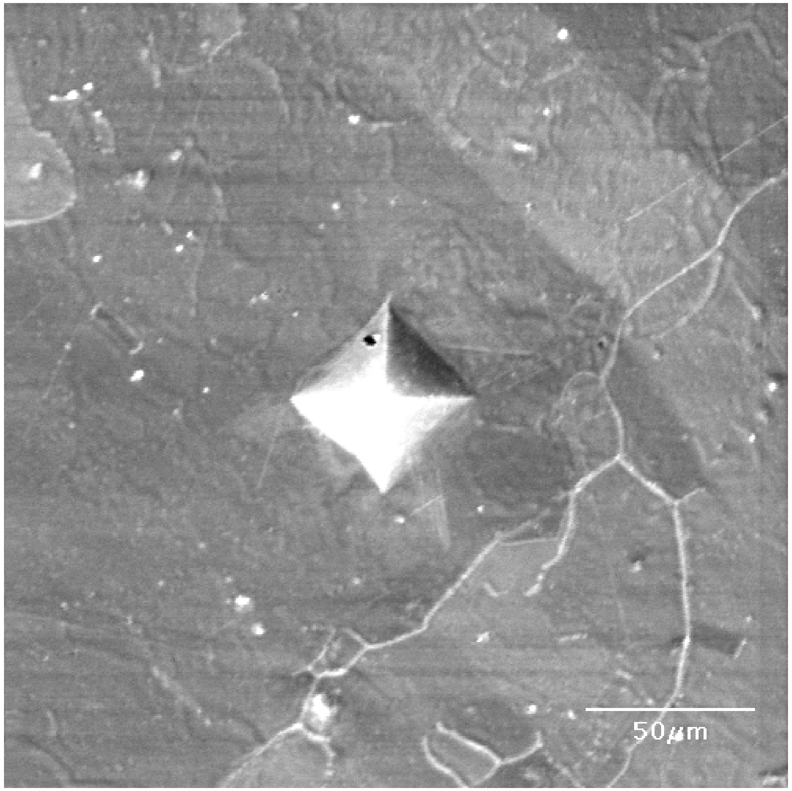
- 10in long, 4in diameter cylinder;
- 316 Stainless steel;
- Annealed polished flat plates at the ends;
- Target geometry similar to one of SNS mercury targets that experienced pitting damage.
- Liquid lead-bismuth eutectic at about 175°C at start.



LBE Target Window Before and After Irradiation

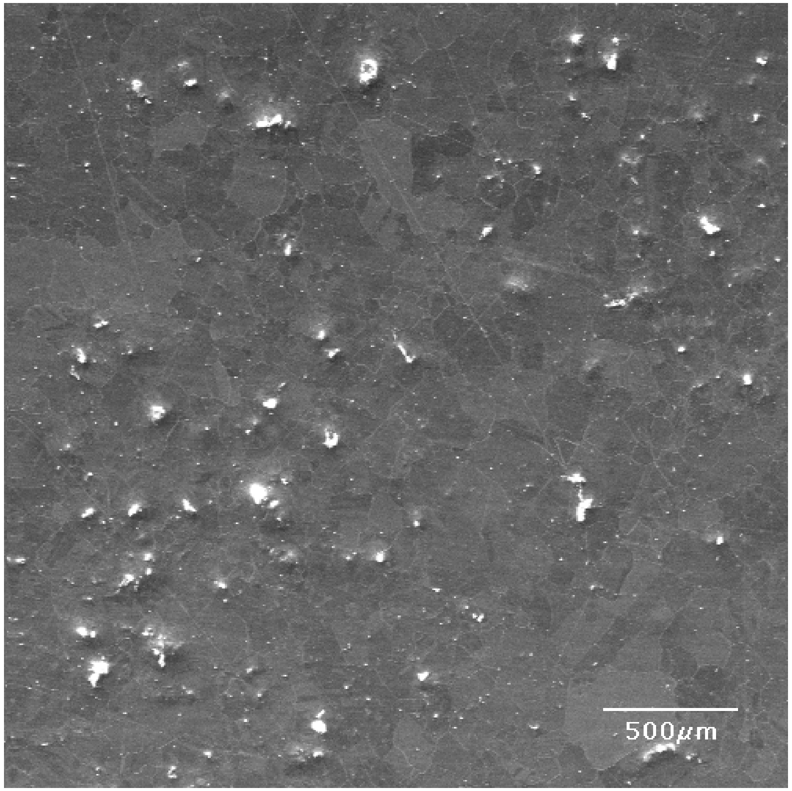


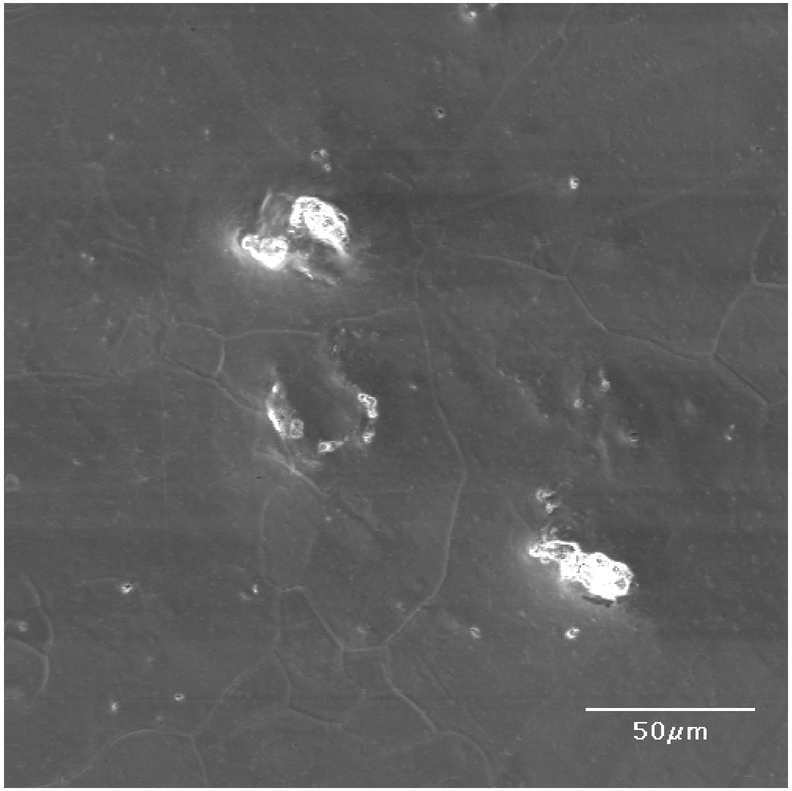
Before irradiation



After irradiation

Cluster of Large Pits





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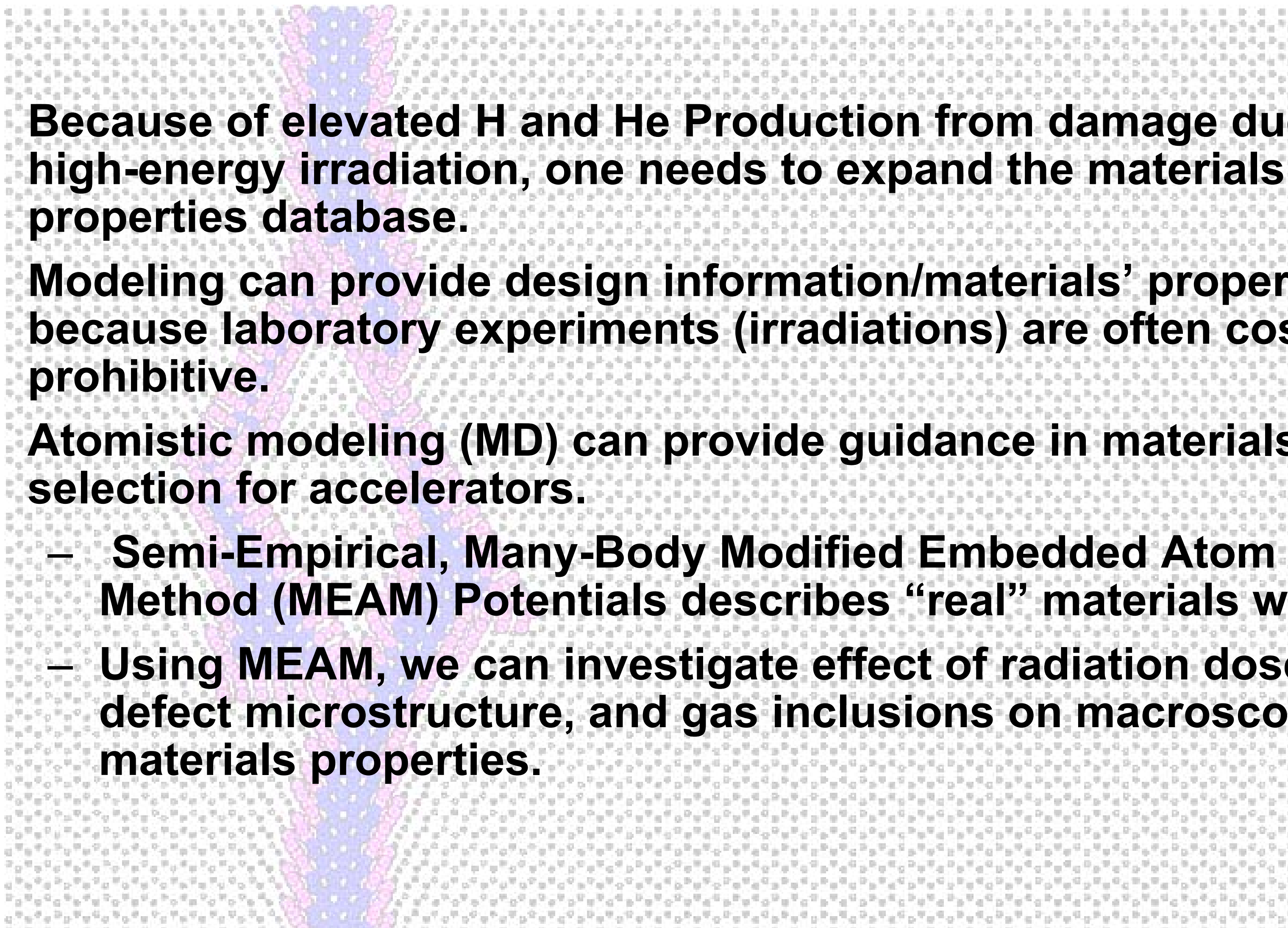
Atomistic Modeling

- **Because of elevated H and He Production from damage due to high-energy irradiation, one needs to expand the materials' properties database.**
- **Modeling can provide design information/materials' properties because laboratory experiments (irradiations) are often cost-prohibitive.**
- **Atomistic modeling (MD) can provide guidance in materials selection for accelerators.**
  - **Semi-Empirical, Many-Body Modified Embedded Atom Method (MEAM) Potentials describes "real" materials well.**
  - **Using MEAM, we can investigate effect of radiation dose, defect microstructure, and gas inclusions on macroscopic materials properties.**



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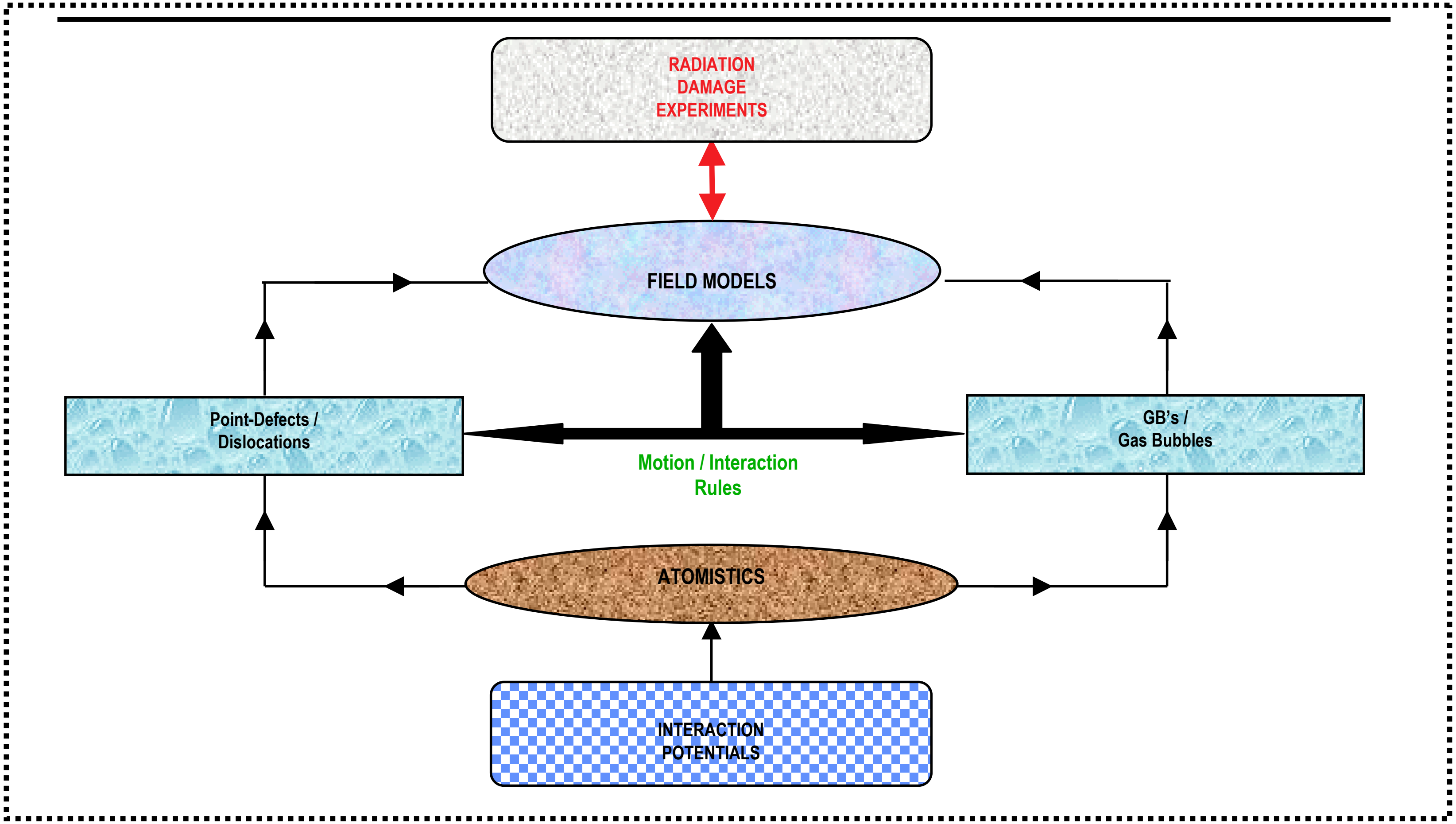
Modeling Radiation Damaged Microstructure



- **The knowledge gained from the atomistic simulations will eventually feed into a "field model" to handle the long-timescales (e.g > nanosecond) to follow the evolution of the microstructure**
- **Ultimately we hope to use these techniques to inform on previous radiation experiments and to extrapolate the materials' properties database to higher temperature and/or dose conditions**

Data is being included in Rev. 3 of the AAA Materials Handbook

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11. Alumina
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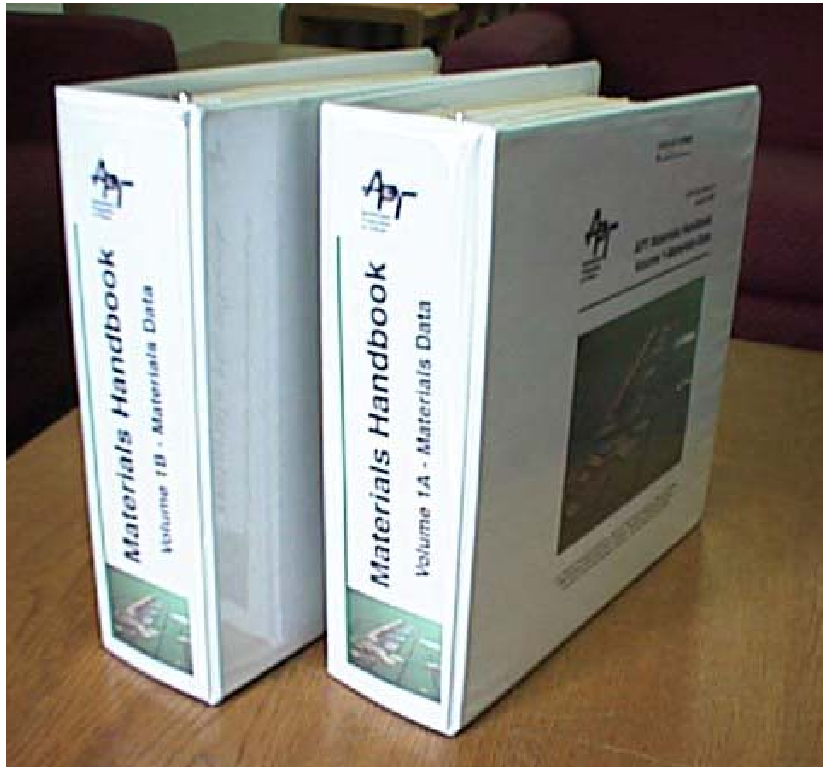
13. Accelerator Component Materials
14. Tritium System Materials
15. Coolants/Fluids
16. 304L SS
17. Shield Block Steels
18. Shield Block Cladding



19. **NEW** Design Properties of Mod 9Cr-1Mo (T91)

20. *(Placeholder)*Design Properties of Russian Ferritic-Martensitic Steels

21. *(Placeholder)* Design Properties of Tantalum

22. **NEW** Design Properties of Lead-Bismuth Eutectic

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